COMPACTION CHARACTERISTICS OF RED MUD AND POND ASH MIX AS FILLING AND EMBANKMENT MATERIAL

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Technology

In

Civil Engineering

(Geotechnical Engineering)

Raj Kishore Bhumij

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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Under the guidance of

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CERTIFICATE

This is to certify that the project entitled "**Compaction Characteristics of Red Mud and Pond Ash Mix As Filling and Embankment Material"** submitted by Mr. Raj Kishore Bhumij (Roll No. 213CE1040) in partial fulfilment of the requirements for the award of Master of Technology Degree in Civil Engineering at NIT Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this report has not been submitted to any other university/institute for the award of any degree or diploma.

Prof. C. R. Patra

Place: Department of Civil Engineering

Date: National Institute of Technology Rourkela

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(Raj Kishore Bhumij)

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Abstract

One of the significant difficulties before the processing and manufacturing industries is disposal of the lingering waste products. Red mud and pond ash are one of the significant waste results of any aluminum industry. The red mud sample is collected from Vedanta Aluminum Ltd., Lanjigarh and pond ash sample is collected from Rourkela Steel Plant, Rourkela. They disposed the waste material using the Thick Slurry Disposal System, which empowers fast consolidation of the slurry once disposed at the red mud and pond ash site. The undertaking work concentrates on the suitability of red mud and pond ash obtained are to be utilized for construction of dyke and filling material.

Several attempts have been made in the past for using red mud as design of tailing dam and pond ash as land filling. In the present work, emphasis has been given on application of red mud and pond ash mix as construction of embankment and as filling material.

In the present work, initially red mud and pond ash are examined for the different geotechnical properties. The different trial works incorporate Standard Proctor Test to acquire the maximum dry density (MDD) and optimum moisture content (OMC), specific gravity test. Utilizing the MDD and OMC results, Direct Shear Test, Triaxial Tests of the sample carried to get the shear parameters c and ϕ. The specimens were likewise tried for their Unconfined Compressive Strength Test and permeability characteristics utilizing both steady head and falling head permeameter to get the coefficient of permeability.

After characterization of red mud and pond ash samples for their individual geotechnical properties, the samples were blended in different proportions to get a mix having optimum mix. All the above analyses were carried on every mix to acquire an optimum mix. The outcomes are gathered in graphical form to observe the patterns in the different parameters.

To account the experimental findings, the samples were also observed under Scanning Electron Microscope (SEM). From the mineralogical data, presence of toxic elements is observed. The above analysis and results can help in solving the problem of red mud and ash disposal and to a great extent help in increasing the economic benefit of the alumina and thermal industries.

Keywords: standard proctor test, unconfined compressive strength, shear parameters, Scanning Electron Microscope.

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Organization of thesis

Chapter 1 describes the introductory about the use of red mud and pond ash in various geotechnical purposes. And also states about how we can use these waste material efficiently.

Chapter 2 in this, a detailed review of the literature performed towards using red mud and pond ash in various geotechnical purposes.

Chapter 3 presents a detailed information about the material used and detailed description of test procedure.

Chapter 4 in this chapter the characterization of material is done. Then the optimum mix was found out and comparative study of different mix proportion was done.

Chapter 5 summarizes the findings of the study and scope of the future works.

CHAPTER 1

Introduction

Beneficial use involves the application of a secondary material from an industrial process, which generally may be viewed as a conceivably dangerous waste, as a building block in another process. The major ill effect of these global processes is the generation of extensive amounts of industrial wastes and the issues related with their safe management and disposal. Second issue is the shortage of area, materials and assets for ongoing developmental activities, including infrastructure.

Red Mud is produced during the process for alumina production. Internationally, there are roughly 70 million tons of red mud being produced every year. Contingent upon the crude material handled, 1–2.5 tons of red mud is produced per ton of alumina produced per 1 tons of bauxite. It's a highly alkaline slurry with 15 to 40% solids. Pond ash produced by thermal power plants takes huge disposal area and creates environmental problems like leaching and dusting. When fly ash and bottom ash mix together, are transported in the form of slurry and stored in the lagoons, the deposits is called pond ash. Added to this, in the absence of any technology that can utilize the industrial wastes like red mud and pond ash, the industries have to incur heavy expenses in terms of land and space, economy and government and international norms which causes comprehensive reduction in the profit margin. The undertaking to use the red mud and pond ash to the most extreme conceivable degree is still a noteworthy issue all through the world. To tackle the issue, red mud, pond ash has potential applications in distinctive ranges like structural fills and highway embankment. For fruitful utilization of the waste material as fill in structural designing development, knowledge of compaction characteristics of the fill material is essential to achieve in the field.

The samples collected from the sites are characterized for their geotechnical properties. Tests are conducted to obtain maximum dry density (MDD) and optimum moisture content (OMC) from Standard Proctor Test, the shear strength parameters c and ϕ from Direct Shear Test and

Triaxial Test. The permeability tests also conducted under constant and falling head condition to obtain the coefficient of permeability κ. After the individual parameters are obtained, the next step is to obtain the optimum mix red mud and pond ash so as to get the best result of the mix. To obtain the optimum mix, red mud and pond ash samples are mixed and test by hit and trial basis. The mixes formed hereby are tested for all the above parameters to obtain the optimum mix for the requirement of constructing embankments and filling material.

CHAPTER 2

Review of Literature and Scope of the Present Study

2.1 Introduction

This chapter describes the detailed review of literature performed towards highlighting the need of red mud and pond ash in various geotechnical purposes. A detailed literature about different geotechnical properties and stabilization of red mud and pond ash in the field using different techniques was presented and discussed.

2.2 Different studies on red mud

Miners (1973) observed that red mud consists of sand and silt size particles with clay size up to 20 – 30%, with complete absence of quartz minerals and classified coarse grained fraction as red sand and fine grained as red mud.

Vogt (1974) portrayed in situ undrained shear qualities are commonly high contrasted with uncemented, clayey soils at identical liquidity indices. The sensitivities vary from 5 to 15 with very high friction angles (φ) of 38-42° are also found for red mud.

Somogyi and Gray (1977) described red mud is of highly alkaline, having 20-30% clay sized particles, with the majority of particles in the silt range. One-dimensional compression tests indicate values for C_c ranging from 0.27 to 0.39 permeability k from 2 to 20 x 10^{-7}cm/s and C_v = 3 – 50 x 10^3 cm^2/s.

Vick (1981) observed that red mud is of low plasticity with liquid limit (LL) of 45% and plasticity index (PI) of 10% with relatively high specific gravity (GS) of 2.8-3.3. Because of its absence of clay mineralogy, these wastes show numerous geotechnical properties like clayey tailings found in other mineral processing [e.g., mineral sands, gold, etc.].

Newson *et al*. (2006) stated that red mud has compression behavior similar to clayey soils, but frictional behavior closer to sandy soils. The red mud appears to be "structured" and has features consistent with sensitive, cemented clay soils. Chemical testing suggests that the agent causing the aggregation of particles is hydroxysodalite and that the bonds are reasonably strong and stable during compressive loading. Exposure of the red mud to acidic conditions causes dissolution of the hydroxysodalite and a loss of particle cementation. Hydration of the hydroxysodalite unit cells is significant, but does not affect the mechanical performance of the material.

Kalkan (2006) stated that the potential use of red mud for the preparation of stabilization material is presented in this study. This study examines the effects of red mud on the unconfined compressive strength, hydraulic conductivity, and swelling percentage of compacted clay liners as a hydraulic barrier. The test results show that compacted clay samples containing red mud and cement–red mud additives have a high compressive strength and decreased the hydraulic conductivity and swelling percentage as compared to natural clay samples.

Kirkland (2009) stated that use of a leaching assessment framework as input for beneficial use determinations for use of red mud and phosphogypsum as alternative construction materials. The leaching tests were performed on two mixtures of red mud and phosphogypsum. Examination of calculated dilution/attenuation factors show that constituent leaching from these two secondary materials would likely not exceed water quality limits under credible environmental scenarios. This study provides an indication that advanced leaching tests can facilitate evaluation of potential environmental impacts in a beneficial use scenario.

Wang and Liu (2012) stated that performances of two common types of red mud, Bayer red mud and Sintering red mud, were investigated. Their compositions, mechanical properties and microstructure characterization were measured through XRD, TG and SEM analysis. Their shear strength, particle size, density and hydraulic characteristics also had been performed. The micro particle of Bayer red mud is finer and more disperse, but the Sintering red mud has higher shear strength. Combining the TG and hydraulic characteristics analysis, it can be shown that Bayer red mud has higher value of water content and Sintering red mud has higher hydraulic conductivity. Sintering red mud can become the main filling material of supporting structure of red mud stocking yard. Bayer red mud has a high reuse value and also can be used as a mixing material of masonry mortar.

Rout *et al*. (2012) stated that red mud can be used as an alternate embankment material, based on laboratory findings and finite element analysis. The geotechnical properties such as specific gravity, classification, compaction characteristics, triaxial shear strength and dispersion properties of red mud are discussed. A comparison is made with the properties of fly ash. A method to prevent dispersion of red mud and stability analysis of the embankment using finite element analysis with static and dynamic load is also presented.

Satyanarayana *et al*. (2012) investigated feasibility of red mud as road construction. Red mud was stabilized with 2, 4, 6, 8, 10, 12 percentage of lime and unconfined compressive strength, split tensile strength, and California Bearing Ratio tests were conducted at 1, 3, 7 and 28 days curing period respectively. From the experimental findings it is observed that 10 percentage lime content has higher values as compared to other percentages. At 28 days it has shown maximum values than other curing periods of all other percentages of lime.

Rout *et al*. (2013) stated that use of red mud for construction of tailing dam based on laboratory findings and finite element analysis. The geotechnical properties such as plasticity, compaction, permeability, shear strength characteristics and dispersion of red mud are presented. Stability and seepage analysis of tailing dams as per finite element analysis using the above geotechnical parameters is presented.

Kola and Das (2013) found out the lateral earth pressure due to red mud on a retaining wall using laboratory findings and using commercial available software. The analyses were carried out with the help of PLAXIS the commercial software used in various geotechnical engineering problems.

Rai *et al*. (2013) stated that red mud is a highly alkaline waste generated from alumina refinery with a pH of 10.5–12.5 which poses serious environmental problems. Neutralization or its treatment by sintering in presence of additives is one of the methods for overcoming the caustic problem as it fixes nearly all the leachable free caustic soda present in red mud. Feasibility of reducing the alkaline nature of red mud by sintering using fly ash as an additive via Taguchi methodology and its use for brick production.

Deelwal *et al*. (2014) stated that basics properties like Specific gravity, Particle size distribution, Atter Berg's limit, OMC and MDD are determined. Engineering properties like shear strength, permeability and CBR values are also determined in conformity with the Indian Standard Code. It revealed that the behavior of red mud is likely as clay soil with considerably high strength compared to conventional clay soil.

2.3 Different studies on pond ash

Bera *et al*. (2007) stated that the effects of different compaction controlling parameters, viz. compaction energy, moisture content, layer thickness, mold area, tank size, and specific gravity on dry density of pond ash are discussed. The maximum dry density and optimum moisture content of pond ash vary within the range of 8.40–12.25 kN/ m^3 and 29–46%, respectively. The degree of saturation at optimum moisture content of pond ash has been found to vary within the range of 63–89%. An empirical model has been developed to estimate dry density of pond ash, using multiple regression analyses, in terms of compaction energy, moisture content, and specific gravity.

Jakka *et al*. (2010) stated that the liquefaction behavior of pond ash by conducting cyclic triaxial tests on inflow and outflow ash samples collected from two different ash ponds. Distinctly different liquefaction phenomenon was observed for the ash samples from inflow and outflow points of the same ash pond. Inflow samples exhibited higher cyclic resistance than outflow samples and their strengths were comparable with the natural sands. The influence of various factors on liquefaction susceptibility of both the types of ashes is similar to that of natural sands.

Jakka *et al*. (2010) stated that strength and other geotechnical characteristics of pond ash samples, collected from inflow and outflow points of two ash ponds in India, are similar to sandy soils in many aspects. Strength characteristics were investigated using consolidated drained (CD) and undrained (CU) triaxial tests with pore water pressure measurements, conducted on loose and compacted specimens of pond ash samples under different confining pressures.

Ghosh (2010) stated that Class F pond ash alone and stabilized with varying percentages of lime (4, 6, and 10%) and phosphogypsum (PG) (0.5 and 1.0), to study the suitability of stabilized pond ash for road base and sub base construction. Standard and modified Proctor compaction tests have been conducted to reveal the compaction characteristics of the stabilized pond ash. Both unsoaked and soaked bearing ratio tests have been conducted. The influence of lime content, PG content, and curing period on the bearing ratio of stabilized pond ash. The empirical model has been developed to estimate the bearing ratio for the stabilized mixes through multiple regression analysis.

Satyanarayana *et al*. (2013) stated that pond ash have been considered as a replacement to natural soils. In this an attempt is made to study pond ash as a geotechnical material. To study pond ash as a geotechnical material for sub-grade and fill material, tests like gradation, compaction, CBR, strength and seepage parameters etc., have been conducted on the sample and compared with sand particles. From the test results it is identified that pond ash can withstand high strength by varying moisture contents, good drainage characteristics and incompressible nature like sand particles.

Singh and Sharan (2014) stated that the effects of compaction energy and degree of saturation on strength characteristics of compacted pond ash. The optimum moisture content and maximum dry densities corresponding to different compactive energies were determined by conventional compaction tests. The shear strength parameters, unconfined compressive strengths (UCS) and California bearing ratio (CBR) values of specimens compacted to different dry densities and moisture content were assessed and reported. The effects of compaction energy and degree of saturation on shear strength parameters i.e. unit cohesion (c_u) and angle of internal friction (ϕ) values and also the UCS values are evaluated and presented.

2.4 Scope of the present study

Red mud and pond ash are located extensively in many places of India occupying vast acres of land and it is likely to be increase in future. Due to scarcity of land, these wastes need to be utilize in various constructional purposes. This study is an attempt to utilize red mud and pond ash combined in embankment and filling material. The objective of this study is mentioned below;

i. To determine the correct proportion of red mud and pond ash mix, which can be used as filling material or embankment material by finding out the compaction characteristics of the red mud and pond ash mix.

ii. To study strength and plasticity characteristics of different mix proportions.

CHAPTER 3

Materials and Methods

3.1 General

This chapter describes the methodology and materials used to achieve the objectives. The main materials characterized in the present study are red mud and pond ash; experimental methodology followed for characterization of these materials are discussed. A brief introduction about the above materials and methodology is presented in the following section in this chapter.

3.2 Materials

3.2.1 Red mud

Red mud is produced during the Bayer's process. With this process, we can extract aluminum hydroxides from bauxites and get alumina, which eventually can be smelted and give aluminum. It is insoluble product after bauxite digestion with sodium hydroxide at elevated temperature and pressure. It is a mixture of compounds originally present in the parent mineral, bauxite, and of compounds formed or introduced during Bayer's cycle. It is a disposed as a slurry having a solid concentration in the range of 10 – 30%, pH in the range of 13 and high ionic strength.

A chemical analysis would reveal that red mud contains silica, aluminum, iron, titanium, calcium as well as an array of minor constituents, namely Na, K, Ni, Cu, Pb, Zn, Cr, V, Ba etc. the variation in chemical composition between different red muds worldwide is high. Mineralogically, red mud has a very high number of compounds present. The more frequent compounds are:

Hematite (Fe_2O_3), goethite ($Fe_{(1-x)}Al_xOOH$) (x = 0 – 0.33), gibbsite ($Al(OH)_3$), boehmite AlO(OH), diaspore (AlO(OH)), calcite ($CaCO_3$), calcium aluminum hydrate

($x.CaO.yAl_2O_3.zH_2O$), quartz (SiO_2), rutile (TiO_2), anatase (TiO_2, $CaTiO_3$, Na_2TiO_3), kaolinite ($Al_2O_3.2SiO_2.2H_2O$), sodalities, aluminum silicates, cancrinite, hydroxycancrinite, hydrogarnet. A wide variety of organic compounds are also present.

These organics compounds giving red mud a distinctive odour, are derived largely from decomposed vegetation and toots. Under the alkaline oxidative conditions existing in the Bayer's process, they breakdown to more simple compounds such as the sodium salts of succinic, acetic and oxalic acids. Predominant among these salts is sodium oxalate.

Red mud is a very fine material in terms of particle size distribution. Typical values would account for 90% volume below 75µm. the specific surface of red mud around $10m^2/g$.

As it is apparent red mud is a highly complex material that differs due to the different bauxites used and the different process parameters. Therefore, red mud should be regarded as a group of materials, having particular characteristics, such as;

i. Produced during Bayer's process.
ii. Water suspensions are highly alkaline.
iii. Mainly composed of iron oxides and have a variety of elements and mineralogical phases.
iv. Relatively high specific surface.

The red mud used in the research study is collected from Vedanta Aluminum Ltd., Lanjigarh, Odisha. About 1 – 2.5 tons of red mud is generated per ton of alumina produced per 1 tons of bauxite. The red mud is discharged in a slurry form in to red mud pond.

The red mud is collected from the red mud pond and dried in the oven 105° – 110°C. The physical properties were determined and presented in Table – 4.2.

3.2.2 Pond ash

Ash is the primary waste product and residue obtained by burning of coal. The ash formed is disposed by mixing it with water and certain chemicals to render it ecofriendly in the ponds. These ponds are called ash ponds. The disposal system used for dumping coal ash is Thick Slurry Disposal System which uses certain chemical treatment that renders quick consolidation of the ash slurry as soon as it is disposed at the site. The chemical, geotechnical and mineralogical features of ash depends on various factors like:

i. Type of coal used for fuel
ii. Degree of combustion
iii. Disposal system used

The coal obtained from mines can be categorized as:

i. Grade A
ii. Grade B
iii. Grade C
iv. Grade D

The above classification of Indian coal is based on the carbon content, the maximum being in case of grade A and the minimum being for grade D. thus the quantity of ash produced varies according to the grade of coal used for combustion. A coal having maximum carbon content will produce minimum ash and vice versa. The mineralogical aspects of ash varies according to the degree of combustion of coal. For completely burnt coal, the ash primarily consists of P, Al, Fe and Si along with volatile elements. On the other hand, for partially burnt coal, like the one used for production of coke, used in Bayer's process foe alumina production, will consists of C also as residue.

The chemical composition of disposed ash is also affected by the disposal system. The conventional Thin Slurry Disposal System uses minimal chemical treatment. The ash particles are lighter and it takes several days to consolidate in the ponds after being disposed. This system is used in case of most of the manufacturing industries for ash disposal. The other system, as mentioned above, is Thick Slurry Disposal System, uses chemical treatment that causes aggregation of ash particles causing them to be relatively heavier. Also the water content of the slurry is also reduced compared to that of the former system. Due to heavier particles and reduced water content, the slurry disposed consolidates very quickly, within about 24 hrs. of disposal.

The pond ash was collected from Rourkela Steel Plant, Rourkela, Odisha. Pond ash was dried in the oven at 105° – 110°C. The physical properties were determined and presented in Table – 4.4.

3.3 Test procedures and methodology

First of all the basic geotechnical properties of red mud and pond ash was found out. Then strength properties and permeability characteristics was found out. Then mineralogy analysis and particle arrangement of oven dried sample was carried out under X-Ray Diffraction analysis (XRD) and Scanning Electron Microscope (SEM). After that red mud and pond ash were mixed in different proportion. Then the strength and permeability characteristics of different proportion was found out. The details of tests conducted and the experimental procedure are specified below.

3.3.1 Test Procedures

3.3.1.1 Specific Gravity

The specific gravity of red mud and pond ash were determined using pycnometer method as per IS: 2720 – Part 3 (1980).

3.3.1.2 Particle Size Distribution

Particle size distribution of red mud and pond ash was determined using sieve analysis and hydrometer method separately accordance with IS: 2720 – Part 4 (1975). Then both the results combined to draw the particle size distribution curve.

3.3.1.3 Compaction Test

Compaction curves of red mud and pond ash were obtained from standard compaction energies. The water – density relation of red mud and pond ash using light compaction was determined in accordance with IS: 2720 - Part 7 (1983).

3.3.1.4 Unconfined Compressive Strength Test

Unconfined compressive strength (UCS) tests used mostly in order to verify the strength characteristics. Since this test has several advantages such as simple, fast, reliable and cheap. The UCS tests were conducted according to IS: 2720 – Part 10 (1991). The UCS test was performed on samples by using conventional compression testing machine. The size of the tested specimens is 72 mm height and 36 mm diameter. The test was continued till failure or maximum vertical strain according to IS: 2720 – Part 10 (1991) is equal to 20% of the height of the specimen which corresponds to a deformation of 14.4 mm (whichever is earlier). More specifically, unconfined compressive strength of specimen can be defined by the strength corresponding either at the failure stage or at the maximal vertical strain (ε) equal to 20% of the original height whichever occurring first. In the present study, the specimens were shared at a strain rate of 1.2 mm/min.

3.3.1.5 Direct Shear Test

The shear parameters of specimens were determined as per IS: 2720 (Part 13) 1986. The specimens were collected by inserting sampling device of size 60mm×60mm×25mm into the samples collected in the sampler. The specimens were trimmed and levelled prior to testing. All the specimens were sheared at a rate of 0.2 mm/ min in a motorized direct shear machine.

The shear strength parameters (i.e. c and ϕ values) were determined by varying normal stress of 0.5 kg/cm^2, 1kg/cm^2 and 1.5 kg/cm^2.

3.3.1.6 Triaxial Shear Test

The shear parameters of specimens were determined as per IS: 2720 (Part 13) 1986. The size of the tested specimens is 72 mm height and 36 mm diameter. The specimen put inside a rubber membrane. Then the specimen kept inside the pressure cell. A separate compressor is used to apply fluid pressure inside the cell. A stainless steel piston running through the centre of the top cap applies the vertical compressive load (called the deviator stress) on the specimen under test. The load is applied through a proving ring with the help of a mechanically operated load frame. Another dial measures the vertical deformations of the specimen during the test. Depending upon the drainage conditions of the test, solid non porous disc or end caps or porous discs are placed on the top and bottom of the specimen.

The cell pressure $\sigma_2 = \sigma_3$ acts all around the specimen; it also acts on the top of the specimen as well as vertical piston meant for applying the deviator stress. The vertical stress applied by the loading frame, is equal to $(\sigma_1 - \sigma_3)$ so that the total stress on the top of the specimen = $(\sigma_1 - \sigma_3) + \sigma_3 = \sigma_1$ = major principal stress. The principal stress difference $(\sigma_1 - \sigma_3)$ is called deviator stress recorded on the proving ring dial.

A particular confining pressure (σ_3) i.e. 100 kg/cm^2 , 200 kg/cm^2 and 300 kg/cm^2 applied during three different observation, giving the value of other stress σ_1 at failure. A Mohr's circle corresponding to this set of (σ_1, σ_3) can thus be plotted. Thus a number of Mohr's circles corresponding to failure conditions are obtained. A curve tangential to these stress circles gives the failure envelope for the soil under the given drainage of the test.

Shear test can be performed in the triaxial apparatus under all three drainage conditions. For undrained test (UU) solid non – porous end caps are placed on the top and bottom of the specimen. In the consolidated undrained test (CU), porous discs are used. The specimen is allowed to consolidate under the confining pressure by keeping the pore water outlet open. When the consolidation is complete, the pore water outlet is closed and the specimen is sheared under undrained condition. In the drained test, the pore water outlet is kept open throughout the test. The compression test is carries out sufficiently slowly to allow for full drainage during the test.

3.3.1.7 Permeability Test

The coefficient of permeability of specimens were determined as per IS: 2720 (Part 36) 1975. The mix was compacted in a standard permeability mold for same dry density found in standard proctor test for same amount of moisture content. The permeability mold consists of detachable collar, drainage base and cap. Average permeability was determined for each samples by allowing water to flow through the samples under a constant and variable pressure head.

3.3.1.8 pH Test

The pH value of specimens were determined as per IS: 2720 (Part 26) 1987. First the specimens were sieved through 75µ sieve. Then the sample mix with distilled water such that specimen to water ratio should be 1:2.5, then the mix was mixed thoroughly for one hour, then the sample filtered through 42µ filter paper for getting clear sample. Then these samples were tested using a pH meter probe. Three readings were taken for better results.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Huge quantities of red mud and pond ash are produced every year as a residue from alumina and coal based thermal power plants in all over the world. Safe disposal and utilization of such large quantities of waste is a major concern. The percentage utilization of red mud and pond ash is rather limited in India than most of the advanced countries. Red Mud is produced during the process for alumina production. Coal ash is a general term given to both flyash and bottom ash. Normally both fly ash and bottom ash from thermal power plant is sluiced with sufficient amount of water to form fly ash slurry, transported and deposited in pond in the vicinity of plants. Various problems being encountered with the red mud pond and ash ponds including dusting problem, increase the level of solid suspended particulate materials in air. Also, leachates emanating from red mud pond and ash ponds may lead to contamination of surface water and groundwater bodies, as well as soils depending on the amount of toxic elements it contains.

A more economical and suitable soil replacement method such as mixing red mud and pond ash together in suitable proportion and use in construction of embankment and also used as filling material. The variation of strength of different mix proportion are studied. All the results of the above investigation and their corresponding analyses have been presented in different section as mentioned below:

I. Characteristics of material red mud and pond ash.

II. Determination of optimum mix.

4.2 Characteristics of Material Used

4.2.1 Characteristics of Red Mud

4.2.1.1 Physical Properties

Approximately 500 kg of red mud collected in wet form which having average water content more than 25%. The red mud has red in colour.

4.2.1.2 Specific Gravity

The specific gravity of red mud was obtained as per IS: 2720 – Part 3 (1980) and it is found to be 3.00. The specific gravity of red mud is considerably higher than normally available soil. The high specific gravity is due to presence of higher iron content.

4.2.1.3 Atterberg's Limit

Atterberg's limits were find out as per IS: 2720 (Part V) – 1985. And the results are in the table below:

Table 4.1 Consistency limits and Indices of red mud

Limits and Indices	Values
Liquid Limit	29%
Plastic Limit	23%
Plasticity Index	6%

4.2.1.4 Particle Size Distribution

The particle size distribution curve of red mud is shown in fig 4.1. From graph the value of D_{10} (Diameter of particle corresponding to the 10% finer), D_{30} (Diameter of particle corresponding to the 30% finer), D_{60} (Diameter of particle corresponding to the 60% finer) was found out to be 0.082 mm, 0.15 mm and 0.38 mm respectively. The coefficient of uniformity i.e. C_u was found out to be 4.63 and coefficient of curvature i.e. C_c was fount out to be 0.72.

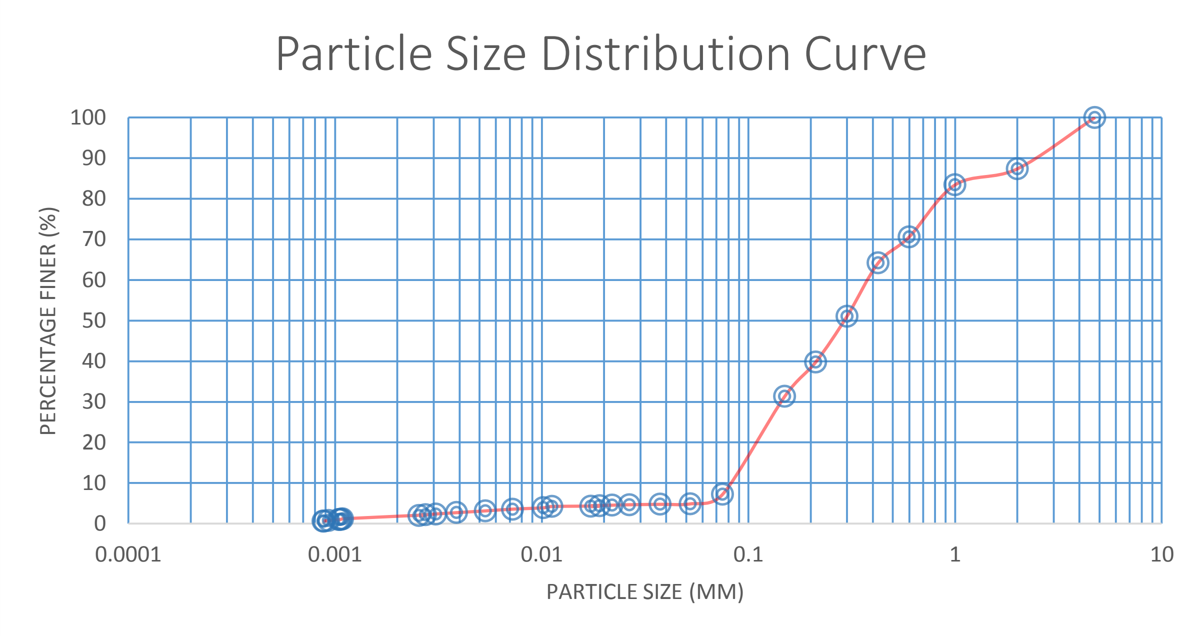


Fig. 4.1 Particle size distribution curve of red mud

Table 4.2 Physical properties of red mud

Physical Parameters	**Values**
Colour	Medium Red
Shape	Angular
Uniformity coefficient (Cu)	4.63
Coefficient of curvature (Cc)	0.72
Specific gravity (G)	3.00
Plasticity Index	Plastic

4.2.1.5 Mineralogy Test

The mineralogy analysis and particle arrangement of oven dried red mud sample are carried out under X-Ray Diffraction analysis (XRD) and Scanning Electron Microscope (SEM). The constituents of various minerals and their proportions in % by weight is as follows:

Element	Weight%	Atomic%
C K	10.95	19.82
O K	37.11	50.43
Na K	5.40	5.11
Al K	10.53	8.48
Si K	4.97	3.84
Ca K	1.50	0.81
Fe K	29.54	11.50
Totals	100.00	

The proportions of different constituent elements is graphically represented as follows:

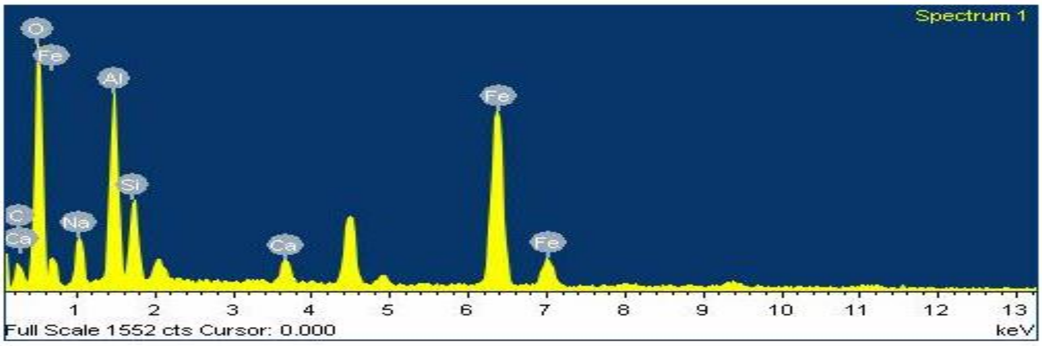


Fig. 4.2 Mineralogy Analysis: Red Mud

The arrangements of particles in the specimen is viewed at a magnification of 1000 at 20kV under the scanning electron microscope at a pressure of 30 kPa. The photograph of the magnified view is as follows:

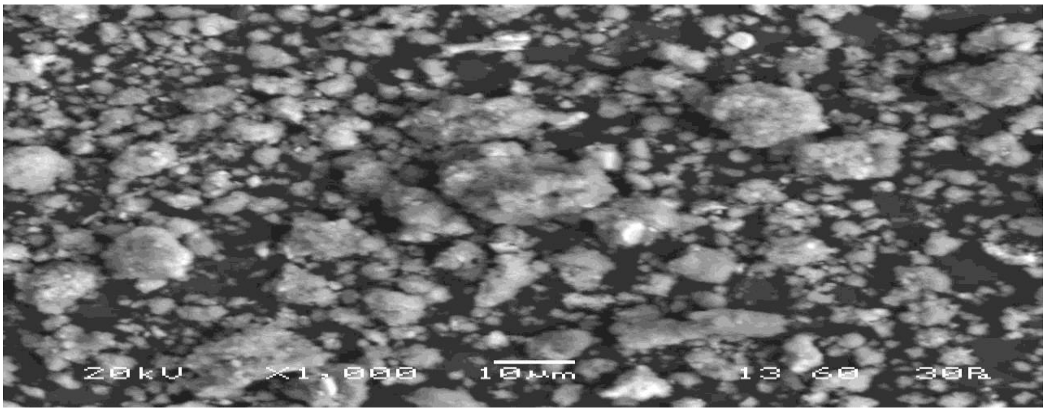


Fig. 4.3 SEM image of red mud

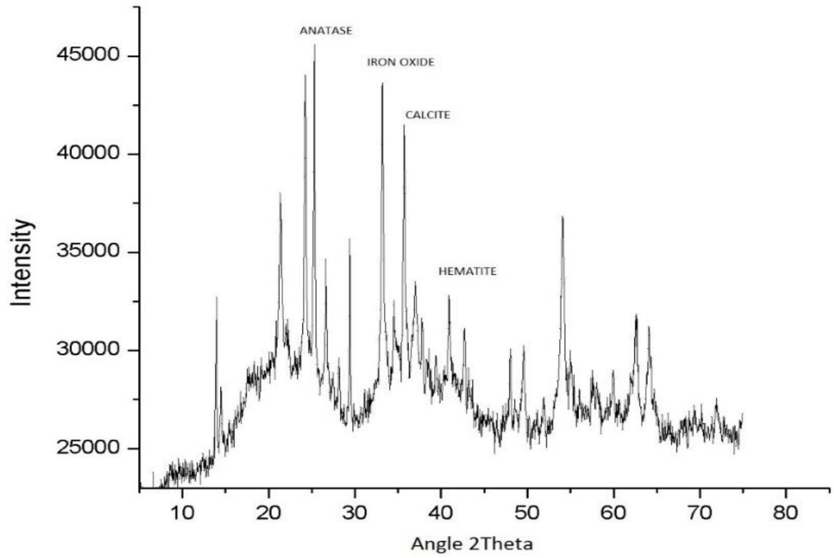


Fig. 4.4 XRD analysis of red mud

From X-Ray Diffraction analysis of red mud it is observed that Hematite, Calcite, Iron Oxide, Anatase are major minerals present in red mud.

4.2.1.6 Engineering Properties

The engineering properties of red mud are shown in the Table 4.2 which includes compaction, strength characteristics and permeability.

Table 4.3 Engineering properties of red mud

Property	Values
1. Compaction Characteristics	
From Light compaction or Standard Proctor test	
a) Maximum Dry Density (kN/m^3)	16.90
b) Optimum Moisture Content (%)	24.63
From Heavy or Modified Compaction test	
a) Maximum Dry Density (kN/m^3)	18.34
b) Optimum Moisture Content (%)	19.00

2. Shear strength parameter from direct shear test a) Cohesion (kN/m^2) b) Frictional angle (ϕ) (degree)	 26.4 34.3
3. Shear strength parameter from triaxial shear test a) Cohesion (kPa) b) Frictional angle (ϕ) (degree)	 27.95 33.2
4. Unconfined Compressive Strength (kN/m^2)	502.46
5. Permeability (cm/sec) of sample a) Under variable head	 1.6×10^{-6}

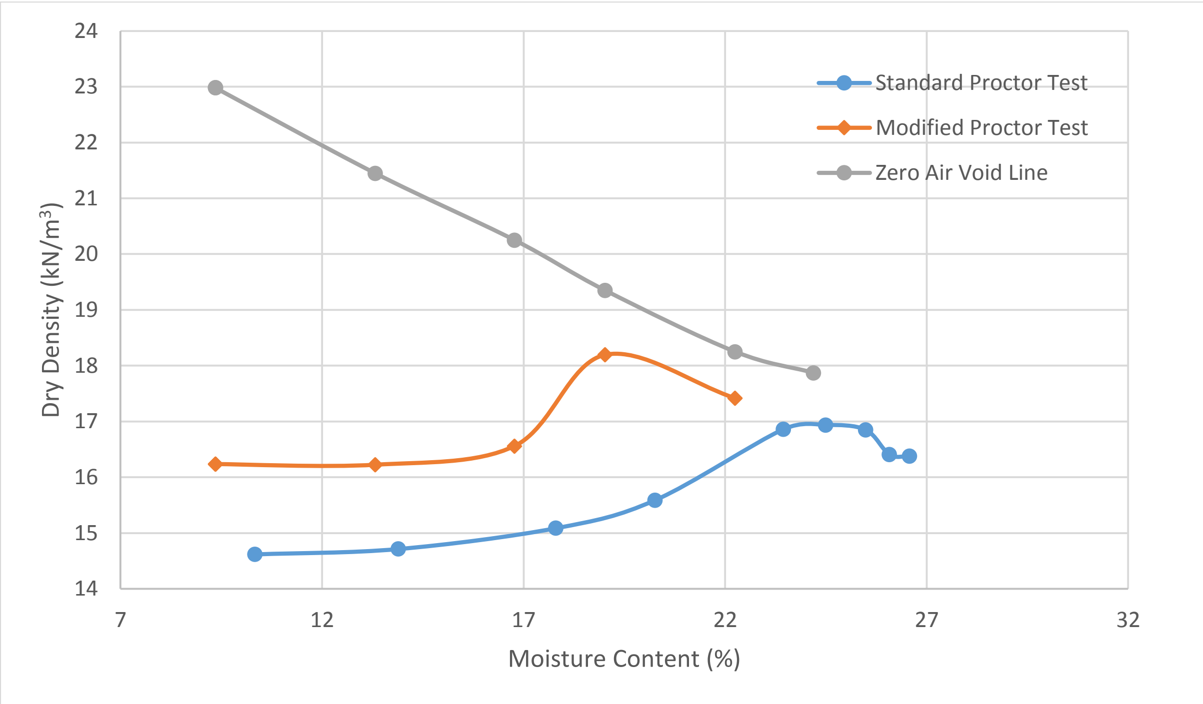


Fig 4.5 Relation between moisture content and dry density of red mud

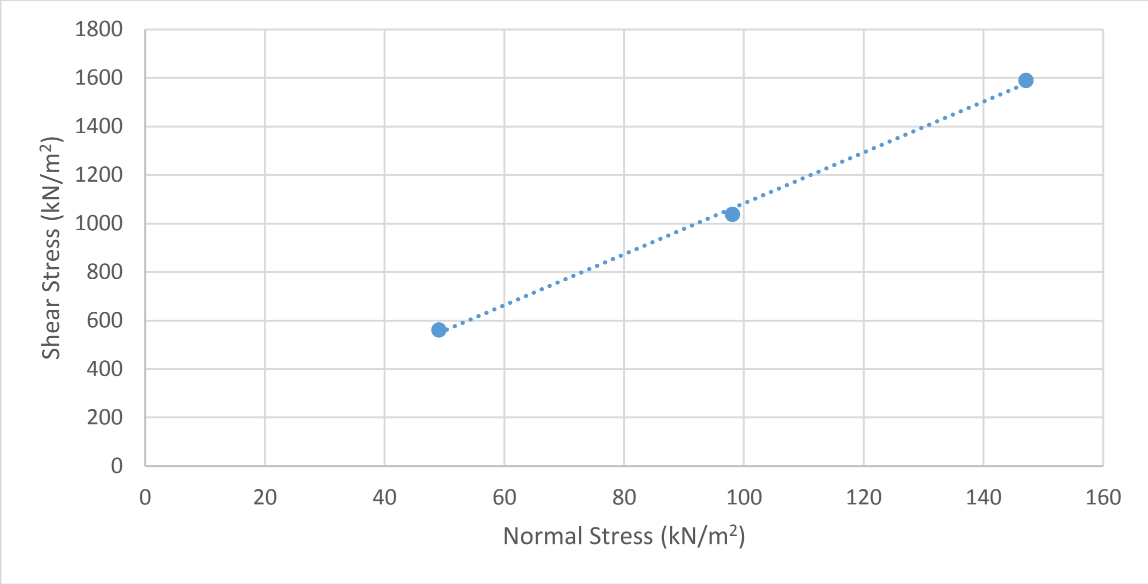


Fig 4.6 Direct shear test of red mud

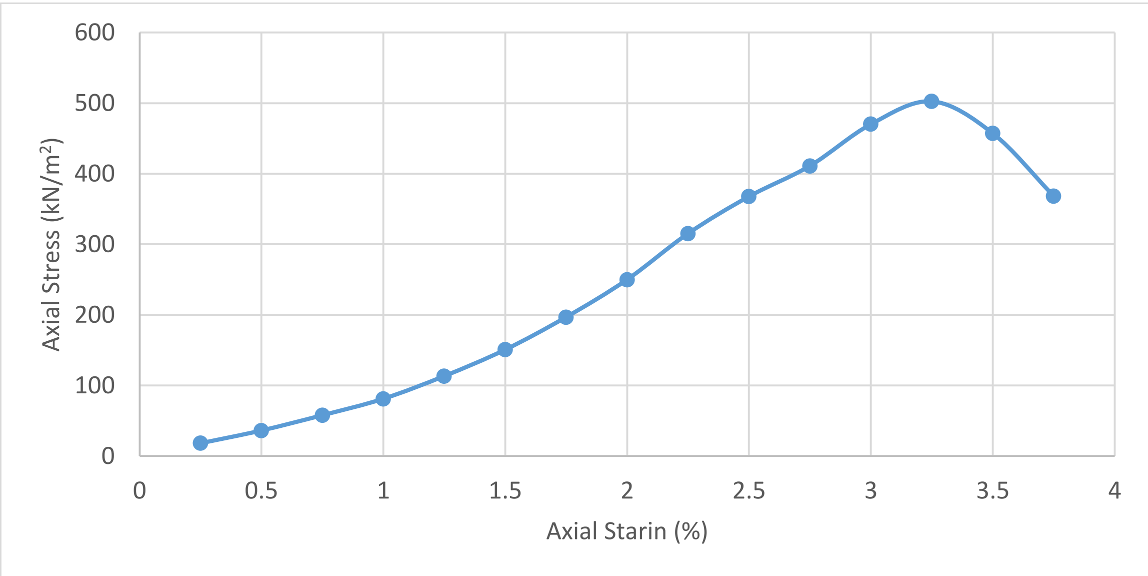


Fig 4.7 Unconfined compressive strength of red mud

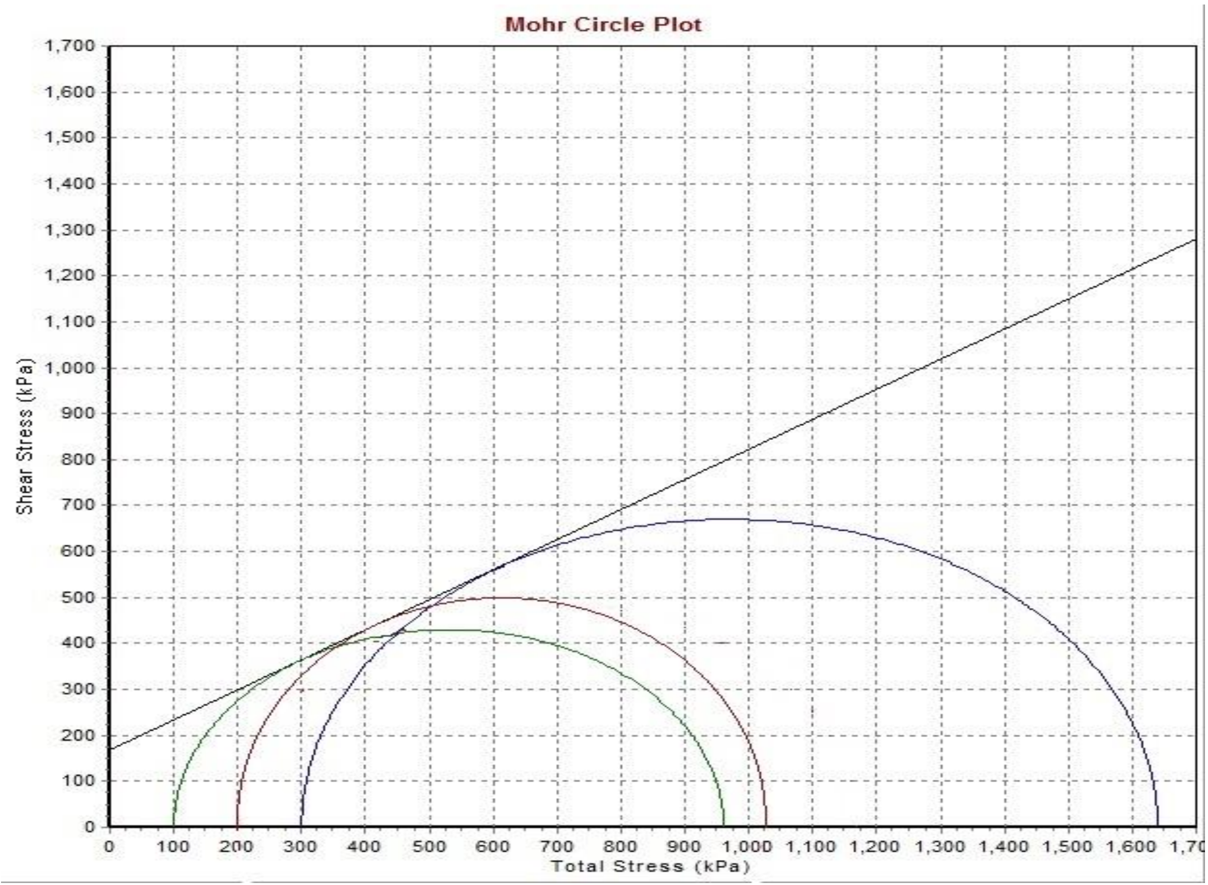


Fig 4.8 Triaxial shear test of red mud

The optimum moisture content of red mud corresponding to maximum dry density in case of standard and modified proctor was found out to be 24.63 % and 19.00 % respectively. And the maximum dry density of red mud in case of standard and modified proctor was found out to be 16.90 kN/m^3 and 18.34 kN/m^3 respectively. Shear strength parameter (c, ϕ) from direct shear test found out to be 34.00 kN/m^2 and the frictional angle of red mud was found out to be 37.3˚, which is higher than locally available soil and from triaxial shear test shear strength parameter (c, ϕ) was found out to be 27.95 kPa and 33.2˚ respectively, which is higher than locally available soil. The unconfined compressive strength of red mud was found out to be 502.46 kN/m^2.

4.2.2 Characteristics of Pond Ash

4.2.2.1 Physical properties of pond ash

Around 500 kg of pond ash was collected from Rourkela Steel Plant, Rourkela which has water content around 20 – 22 % and greyish in colour.

4.2.2.2 Specific Gravity

The specific gravity of pond ash was obtained as per IS: 2720 – Part 3 (1980) and it is found to be 1.97. The specific gravity of pond ash is considerably lower than normally available soil. The low specific gravity is due to presence of small hollow spherical particle called cenospheres and lesser iron content.

4.2.2.3 Particle Size Distribution

The particle size distribution curve of pond ash is shown in fig 4.9. From graph the value of D_{10} (Diameter of particle corresponding to the 10% finer), D_{30} (Diameter of particle corresponding to the 30% finer), D_{60} (Diameter of particle corresponding to the 60% finer) was found out to be 0.018 mm, 0.082 mm and 0.17 mm respectively. The coefficient of uniformity i.e. C_u was found out to be 9.4 and coefficient of curvature i.e. C_c was fount out to be 2.09.

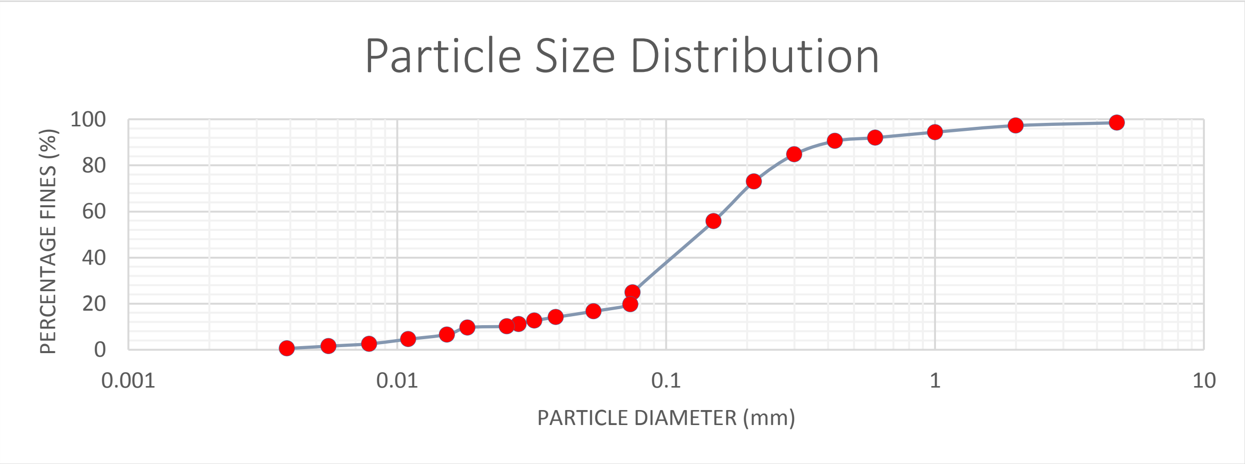


Fig 4.9 Particle size distribution curve of pond ash

Table 4.4 Physical Properties of pond ash

Physical Parameters	**Values**
Colour	Slightly grey
Shape	Rounded / sub rounded
Uniformity coefficient (Cu)	9.4
Coefficient of curvature (Cc)	2.19
Specific gravity (G)	3.00
Plasticity Index	Non plastic

4.2.2.4 Mineralogy Test

The mineralogy analysis and particle arrangement of oven dried pond ash sample are carried out under X-Ray Diffraction analysis (XRD) and Scanning Electron Microscope (SEM). The constituents of various minerals and their proportions in % by weight is as follows:

Element	Weight%	Atomic%
C K	12.13	19.19
O K	45.34	53.86
Al K	14.28	10.06
Si K	20.98	14.20
K K	1.10	0.53
Ti K	1.06	0.42
Fe K	5.12	1.74
Totals	100.00	

The proportions of different constituent elements is graphically represented as follows:

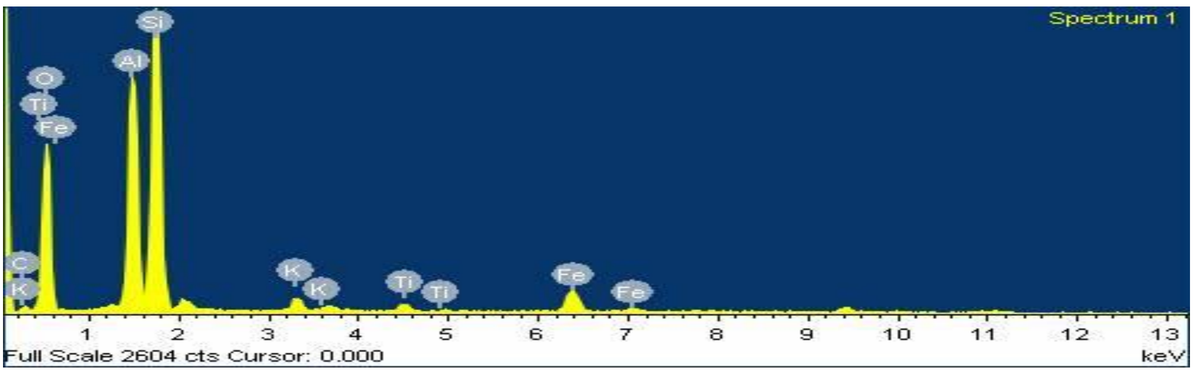


Fig 4.10 Mineralogy Analysis: Pond ash

The arrangements of particles in the specimen is viewed at a magnification of 1000 at 20kV under the scanning electron microscope at a pressure of 30 kPa. The photograph of the magnified view is as follows:

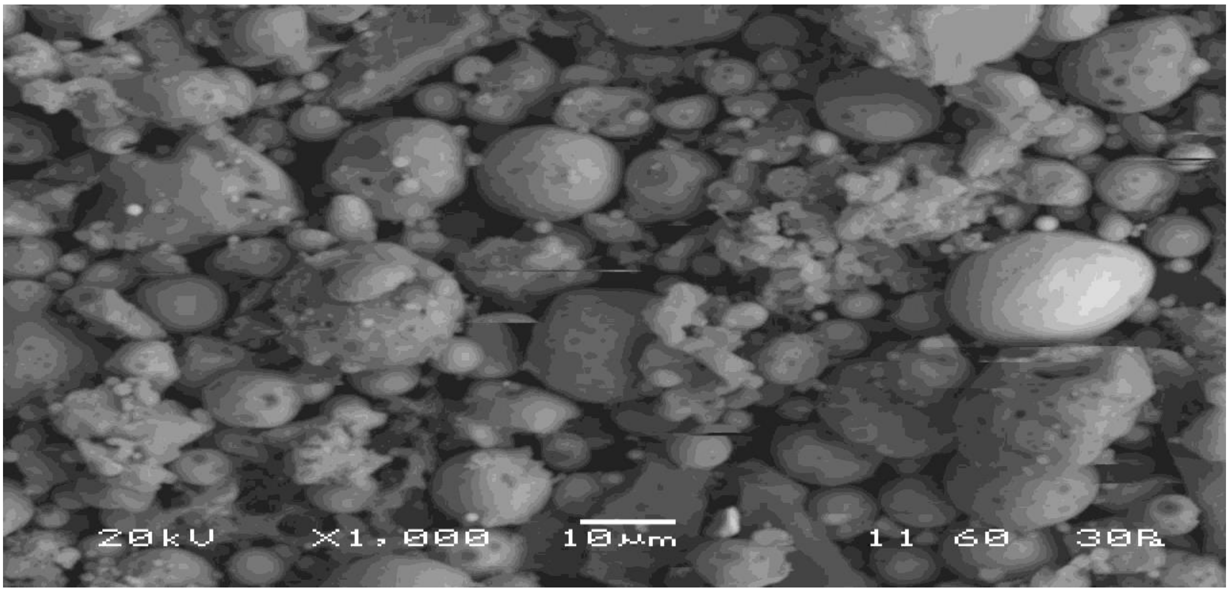


Fig 4.11 SEM image of pond ash

From X-Ray Diffraction analysis of pond ash it is observed that Silicon Oxide, Calcite, Mulite, Manganese Silicon Carbide are major minerals present in pond ash.

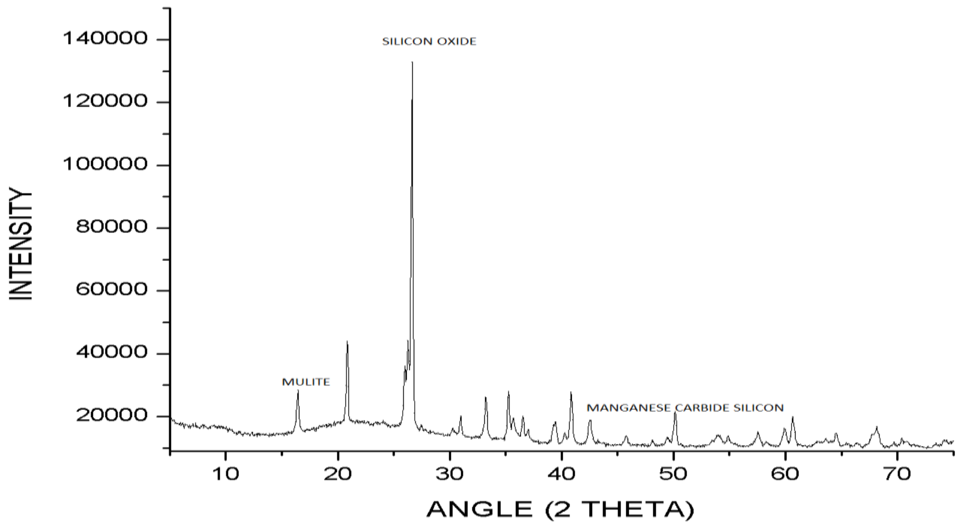


Fig 4.12 XRD analysis of pond ash

4.2.2.5 Engineering Properties

The engineering properties of pond ash are shown in table below which includes compaction and strength characteristics at different states.

Table 4.5 Engineering properties of pond ash

Property	Values
1. Compaction Characteristics From Light compaction or Standard Proctor test a) Maximum Dry Density (kN/m^3) b) Optimum Moisture Content (%)	 10.65 37.52
2. Shear strength parameter from direct shear test a) Cohesion (kN/m^2) b) Frictional angle (ϕ) (degree)	 9.91 32.9
3. Permeability (cm/sec) of pond ash a) Under Variable head	 3.78×10^{-4}

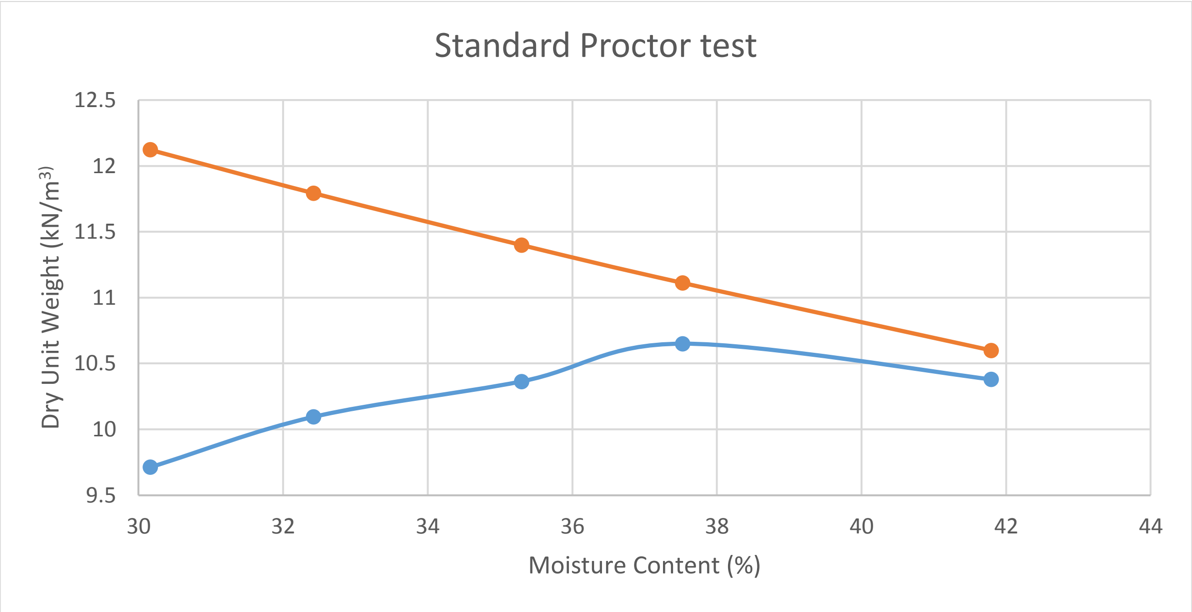
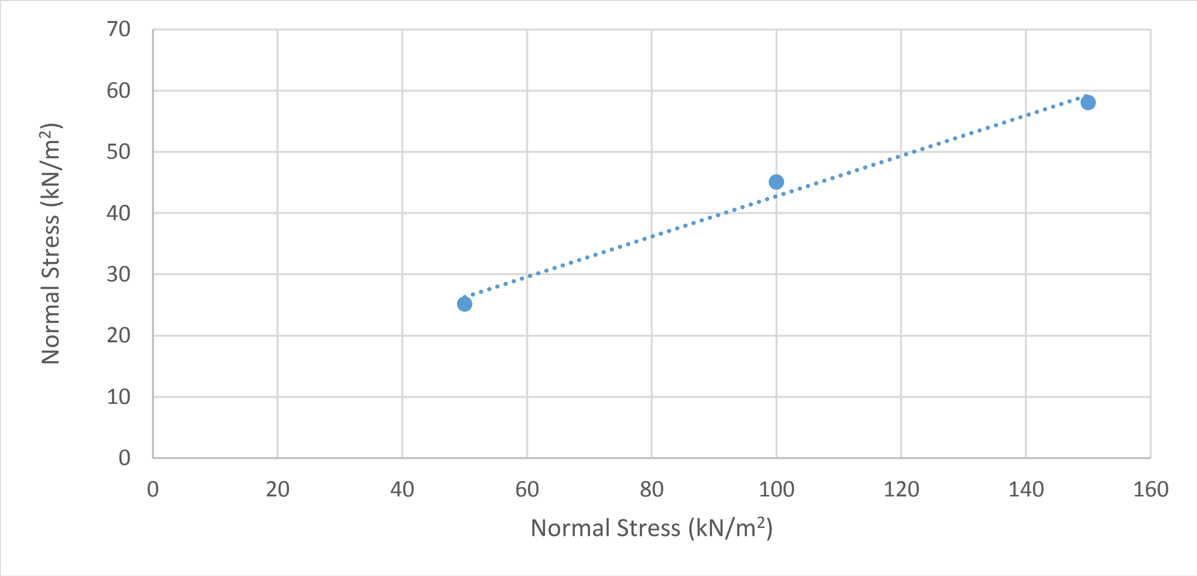


Fig. 4.13 Relation between moisture content and dry density



4.14 Direct Shear Test of pond ash

The optimum moisture content of pond ash corresponding to maximum dry density in case of standard proctor was found out to be 37.52. And the maximum dry density of pond ash in case of standard proctor was found out to be 10.65 kN/m^3. Shear strength parameter (c, ϕ) from direct shear test found out to be 9.91 kN/m^2 and the frictional angle of pond ash was found out to be 32.9˚.

4.2.3 Determination of Optimum Mix

The red mud and pond ash are mixed in various proportions to find out optimum mix proportion in which the geotechnical characteristics are most favorable as filling material or embankment material. The red mud and pond ash are mixed in following proportions.

i. 90% red mud + 10% pond ash

ii. 80% red mud + 20% pond ash

iii. 70% red mud+ 30% pond ash

iv. 60% red mud + 40% pond ash

v. 50% red mud + 50% pond ash

All the above mix proportions are analyzed for their maximum dry density (MDD) and corresponding optimum moisture content (OMC) by standard proctor test. The specific gravity of different mix proportions also determined. After determination of MDD and OMC, the different mix proportions are analyzed for shear strength and cohesion under 2D and 3D failure condition using direct shear box test and triaxial test.

4.2.3.1 Specific Gravity of Different Mix Proportions

The specific gravity of different mix proportions are given in the table below:

Table 4.6 Specific gravity of different mix proportions

Mix Proportions	Specific Gravity
90% red mud + 10% pond ash	2.89
80% red mud + 20% pond ash	2.62
70% red mud + 30% pond ash	2.44
60% red mud + 40% pond ash	2.41
50% red mud + 50% pond ash	2.24

4.2.3.2 Standard Proctor Tests of Different Mix Proportions

The graphs of maximum dry density (MDD) vs. optimum moisture content (OMC) of different mix proportions of red mud and pond ash are as follows:

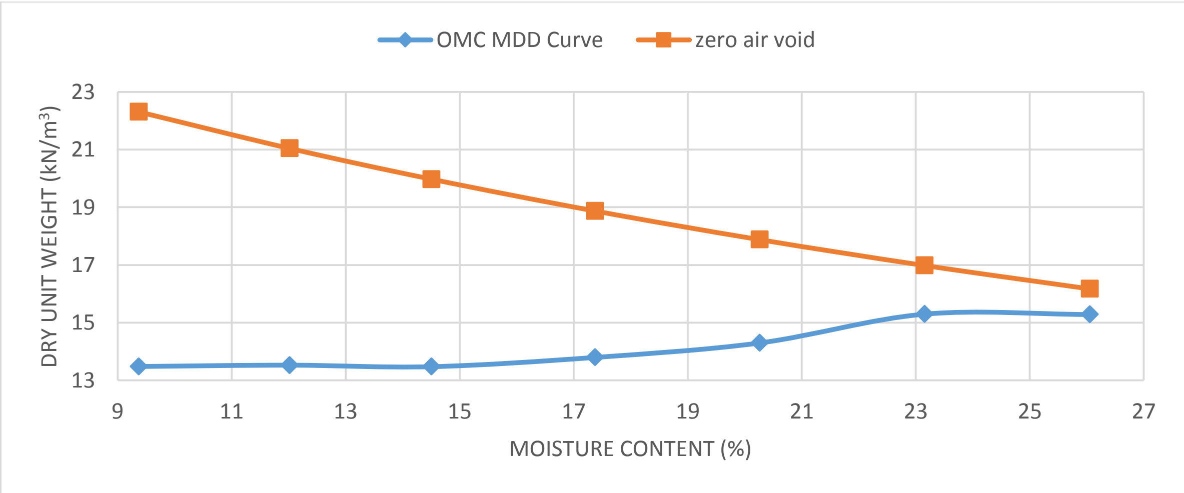


Fig. 4.15 Standard Proctor Test: 90% red mud + 10% pond ash

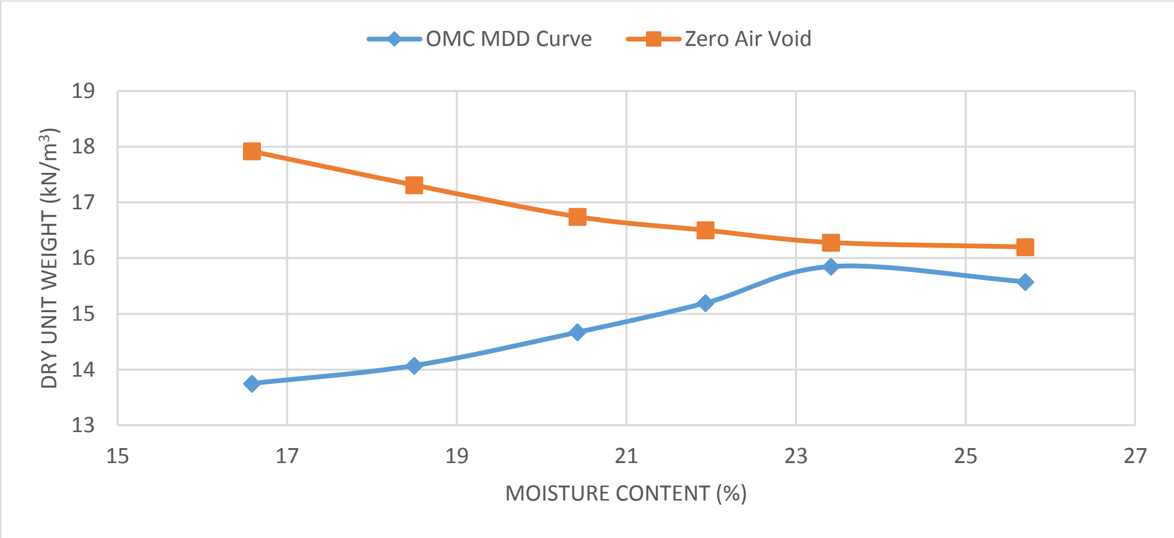


Fig. 4.16 Standard Proctor Test: 80% red mud + 20% pond ash

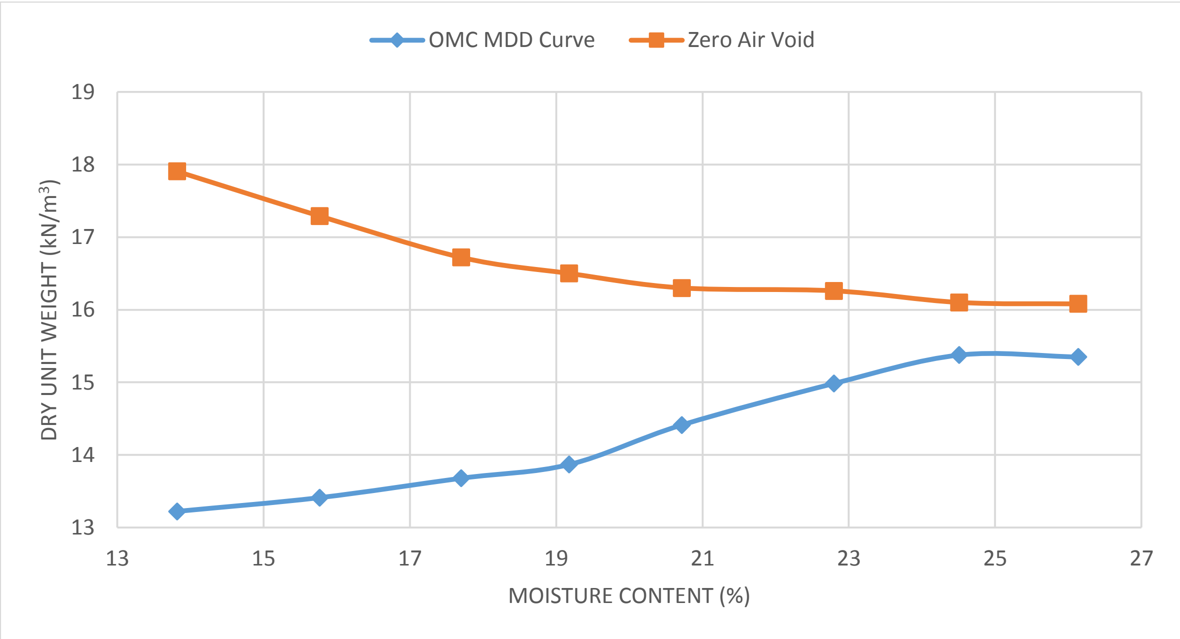


Fig. 4.17 Standard Proctor Test: 70% red mud + 30% pond ash

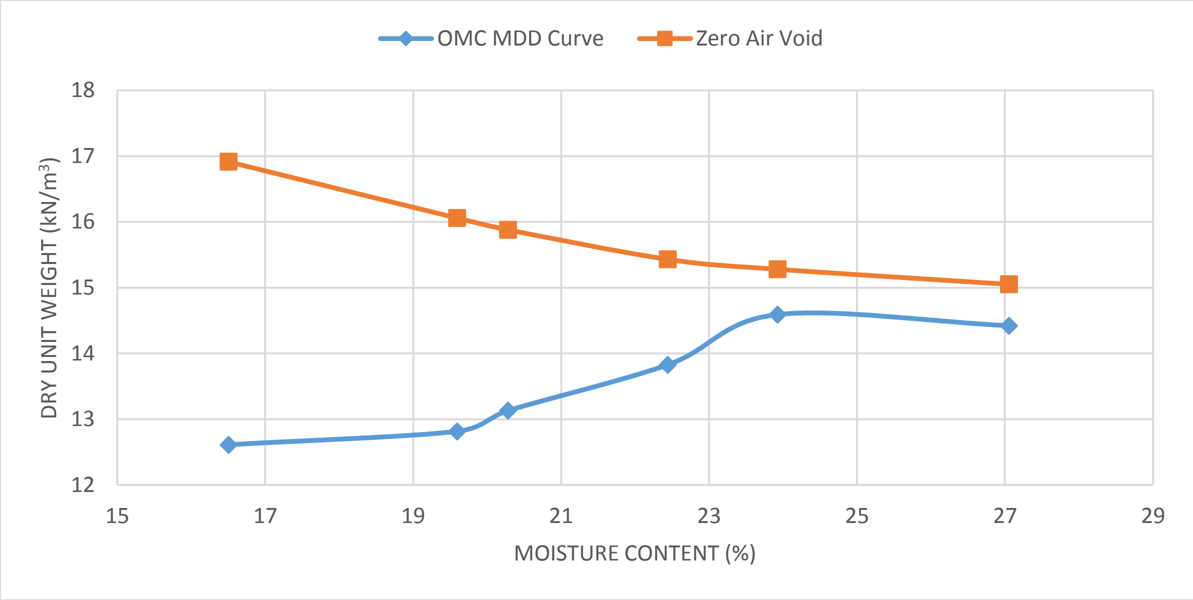


Fig 4.18 Standard Proctor Test: 60% red mud + 40% pond ash

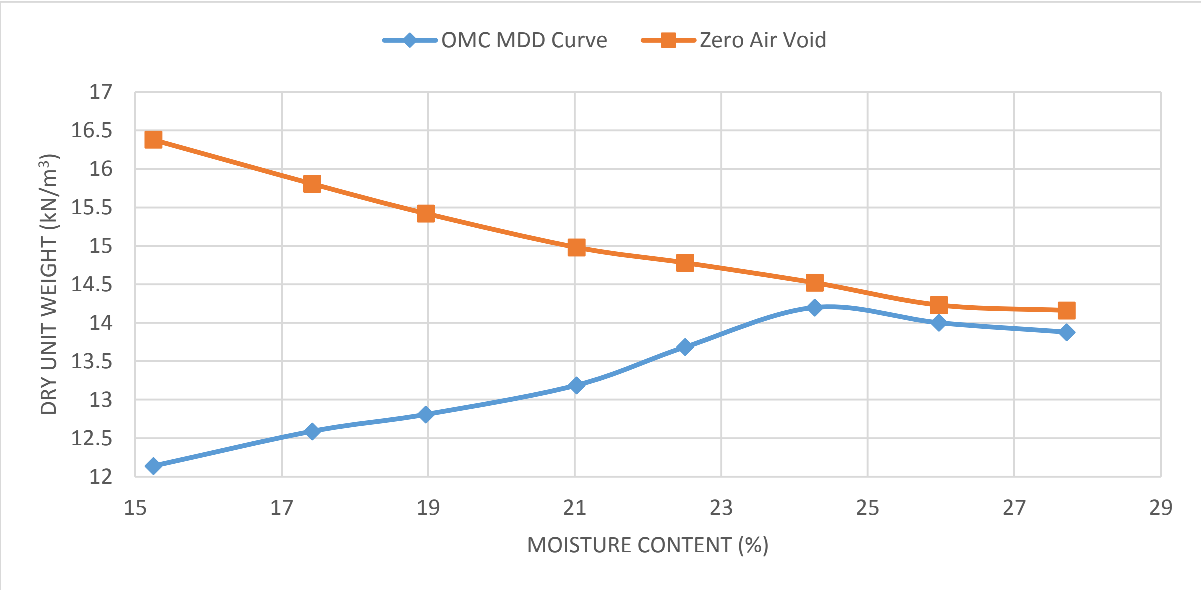
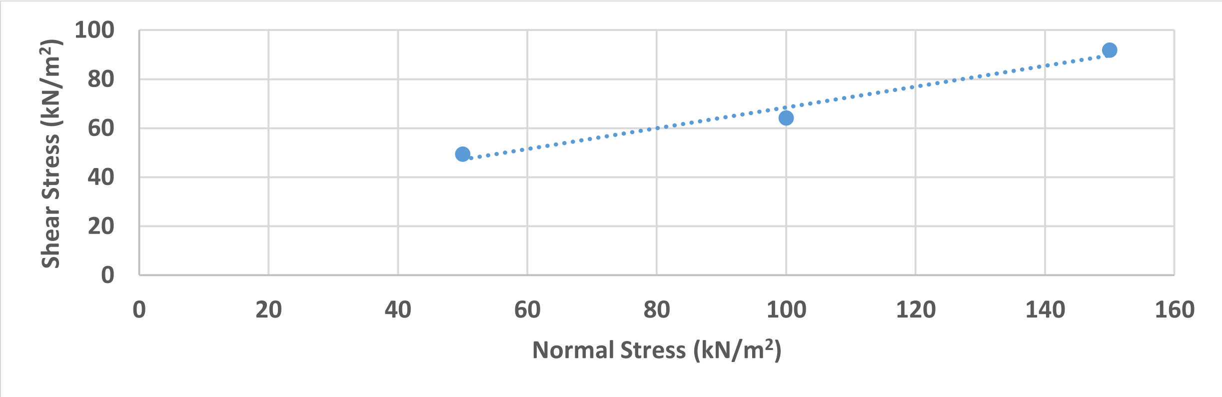


Fig. 4.19 Standard Proctor Test: 50% red mud + 50% pond ash

From the above graphs of dry density vs. moisture content of different mix proportions, the maximum dry density was found out to be 15.84 kN/m^3 and corresponding moisture content was 23%, possessed by the 80% red mud and 20% pond ash mix proportion. The higher density is due better interlocking between red mud and pond ash.

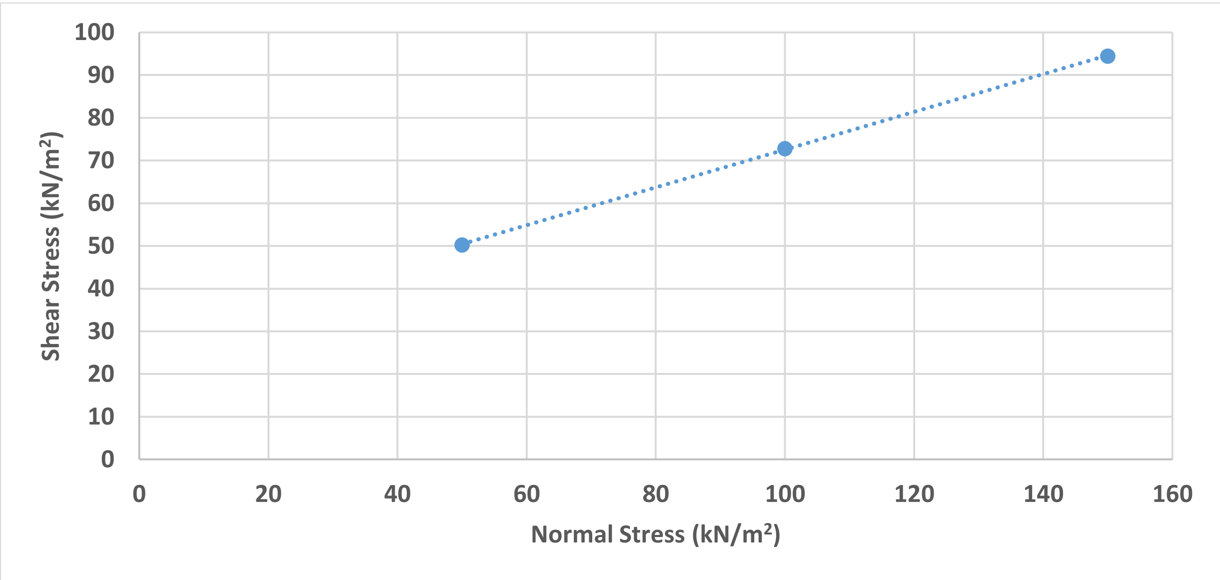
4.2.3.3 Direct Shear Tests of different mix proportions

The direct shear test was done for different mix proportion red mud and pond ash to obtain the shear parameter i.e. angle of internal friction (Φ), cohesion (c) is as follows:



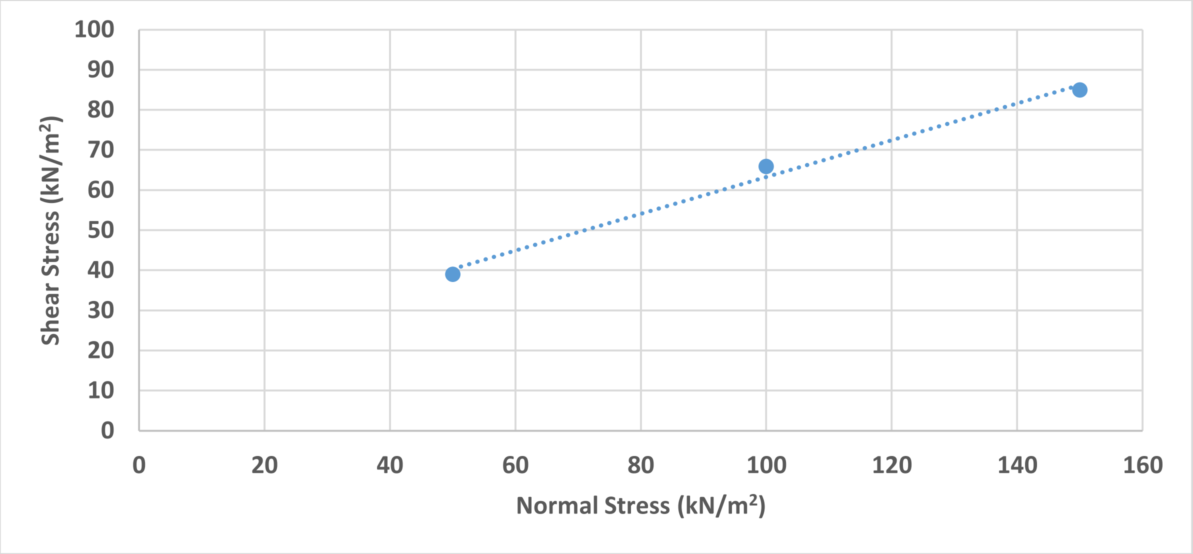
c = 26 kN/m^2, ϕ = 34.4°

Fig 4.20 Direct Shear Test: 90% red mud + 10% pond ash



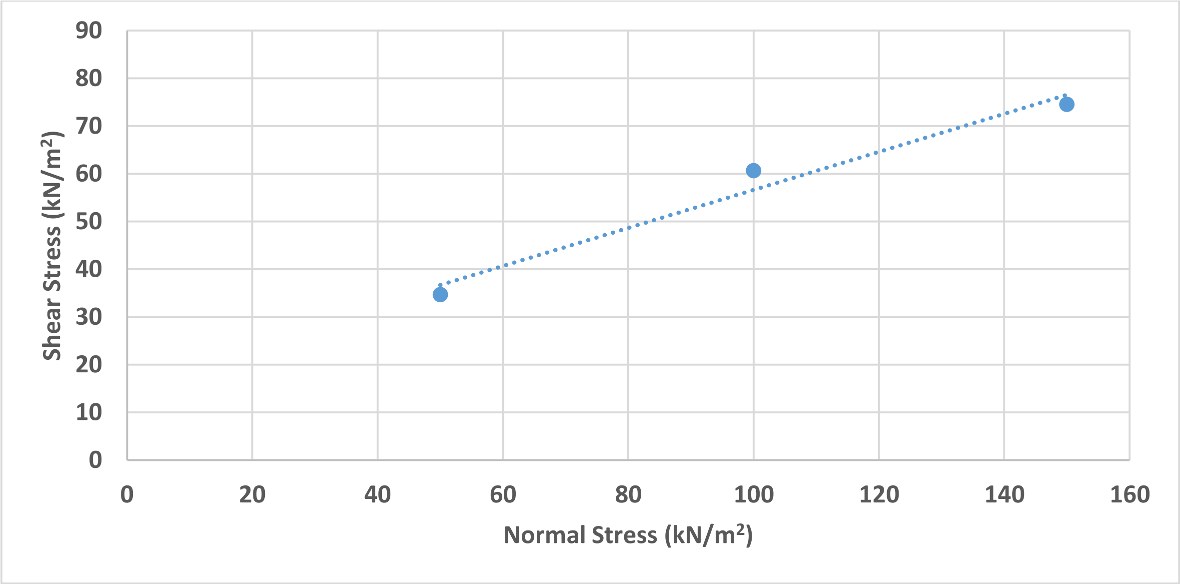
c = 28 kN/m^2, ϕ = 35.9°

Fig 4.21 Direct Shear Test: 80% red mud + 20% pond ash



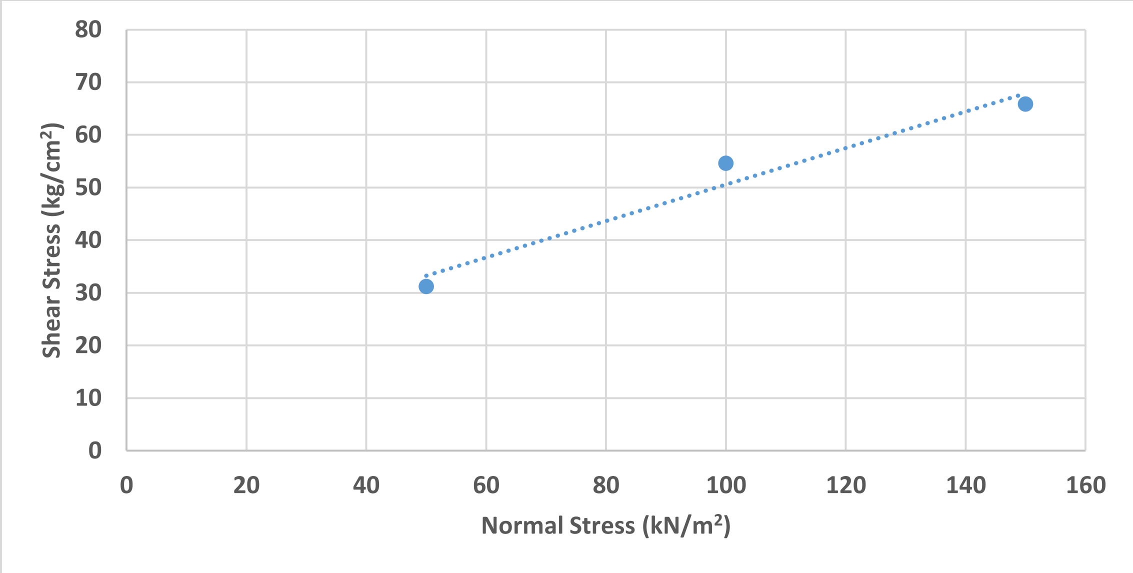
c = 17.3 kN/m^2, ϕ = 32.3°

Fig 4.22 Direct Shear Test: 70% red mud + 30% pond ash



c = 16.7 kN/m^2, ϕ = 29.5°

Fig 4.23 Direct Shear Test: 60% red mud + 40% pond ash



c = 15.9 kN/m^2, ϕ = 26.7°

Fig 4.24 Direct Shear Test: 50% red mud + 50% pond ash

From the above graphs of various mix proportions, the value of cohesion (c) and the angle of internal friction (Φ) is maximum in 80% red mud + 20% pond ash mix as 28kN/m^2 and 35.9° respectively. The higher cohesion value is due to closely packed particle, high surface area to volume ratio and higher angle of friction value is due to better interlocking between paricles and arrangement of particles.

4.2.3.4 Unconfined Compressive strength Test of different mix proportions

The unconfined compressive strength test was done for different mix proportions of red mud and pond ash to obtain the unconfined compressive strength (q_u) as follows:

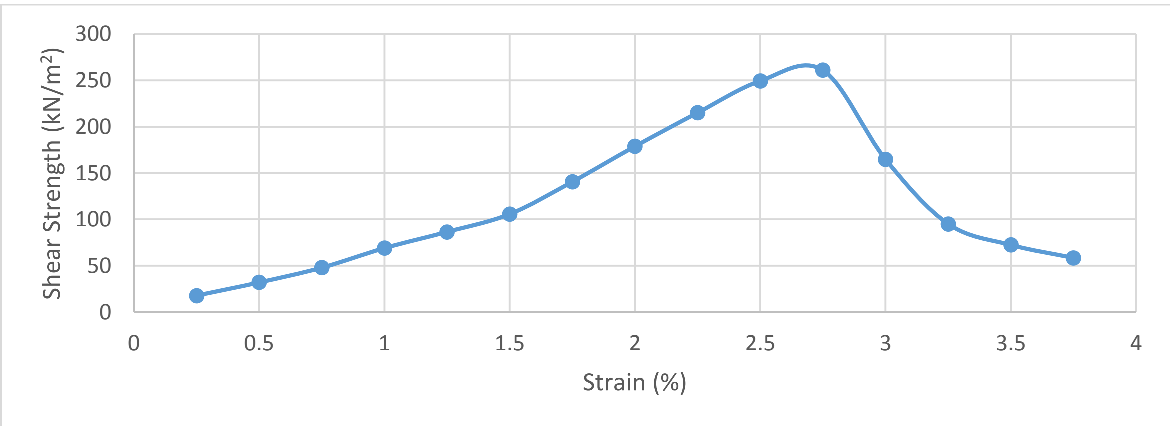


Fig. 4.25 Unconfined Compressive Strength Test: 90% red mud + 10% pond ash

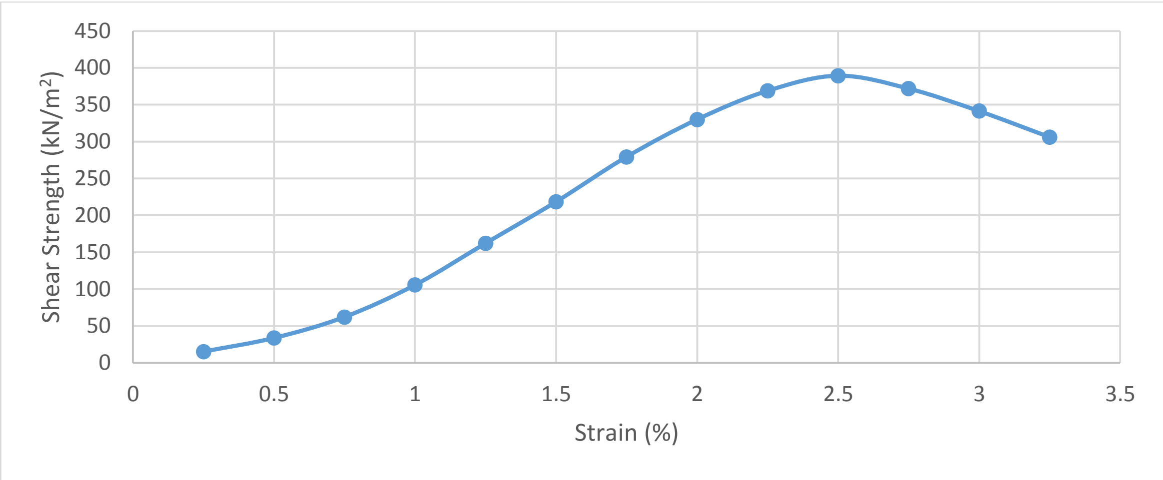


Fig. 4.26 Unconfined Compressive Strength Test: 80% red mud + 20% pond ash

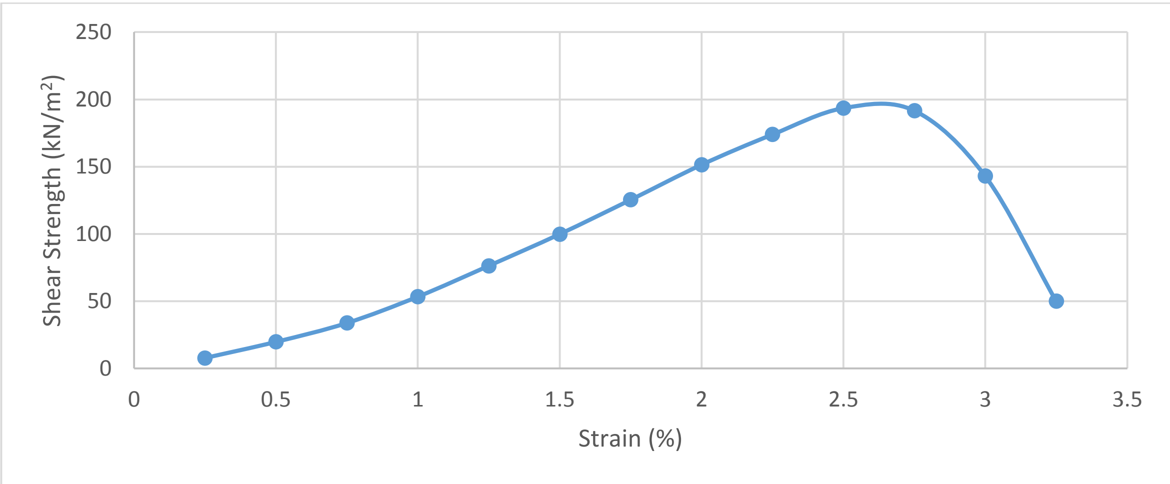


Fig. 4.27 Unconfined Compressive Strength Test: 70% red mud + 30% pond ash

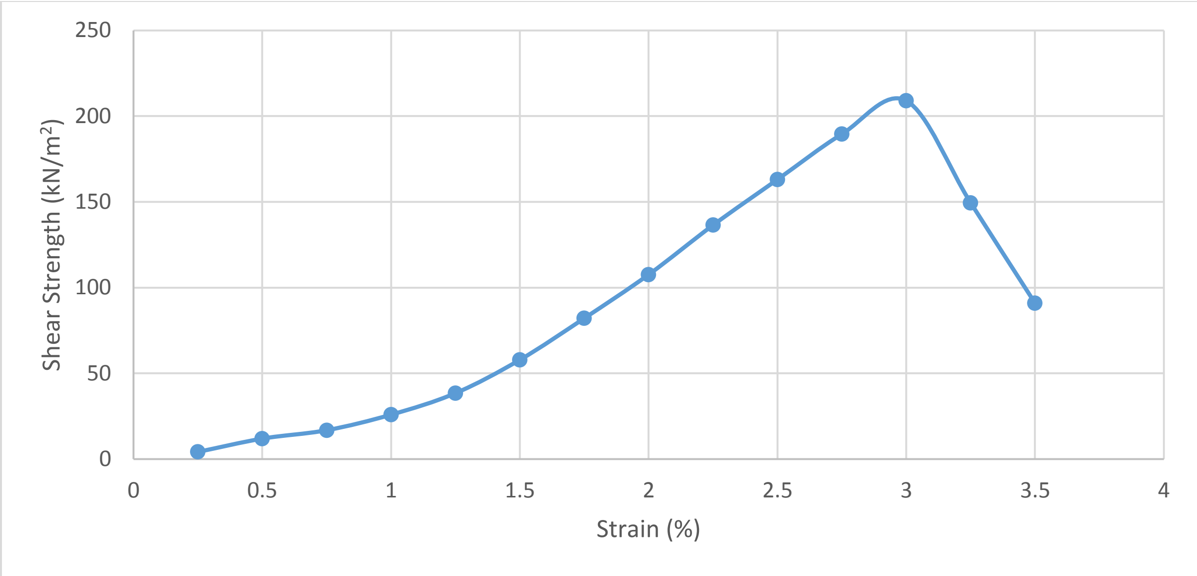


Fig. 4.28 Unconfined Compressive Strength Test: 60% red mud + 40% pond ash

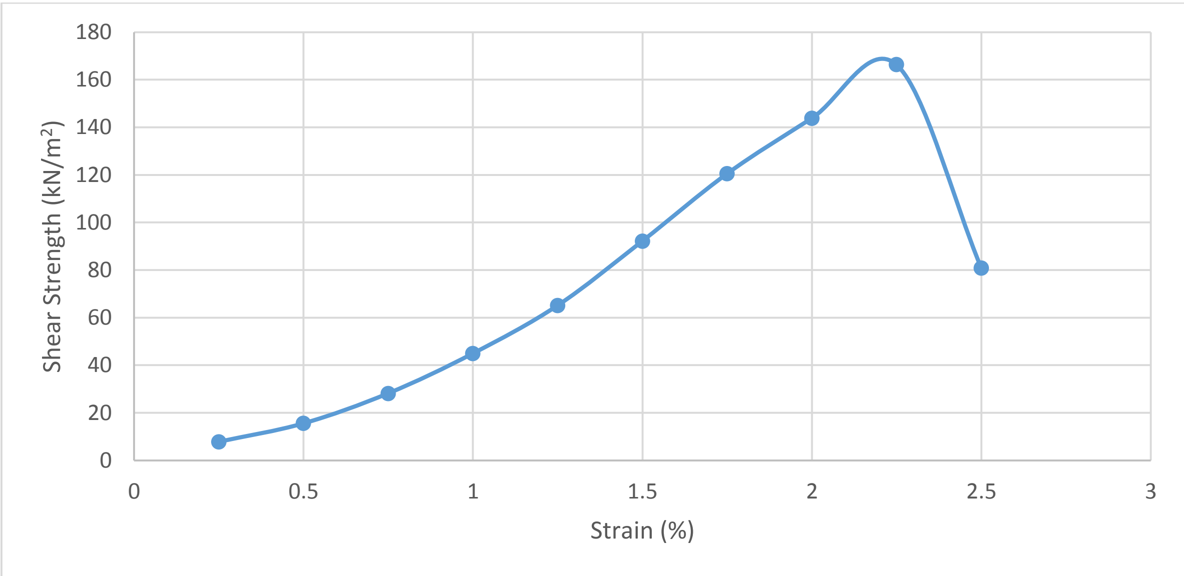


Fig. 4.29 Unconfined Compressive Strength Test: 50% red mud + 50% pond ash

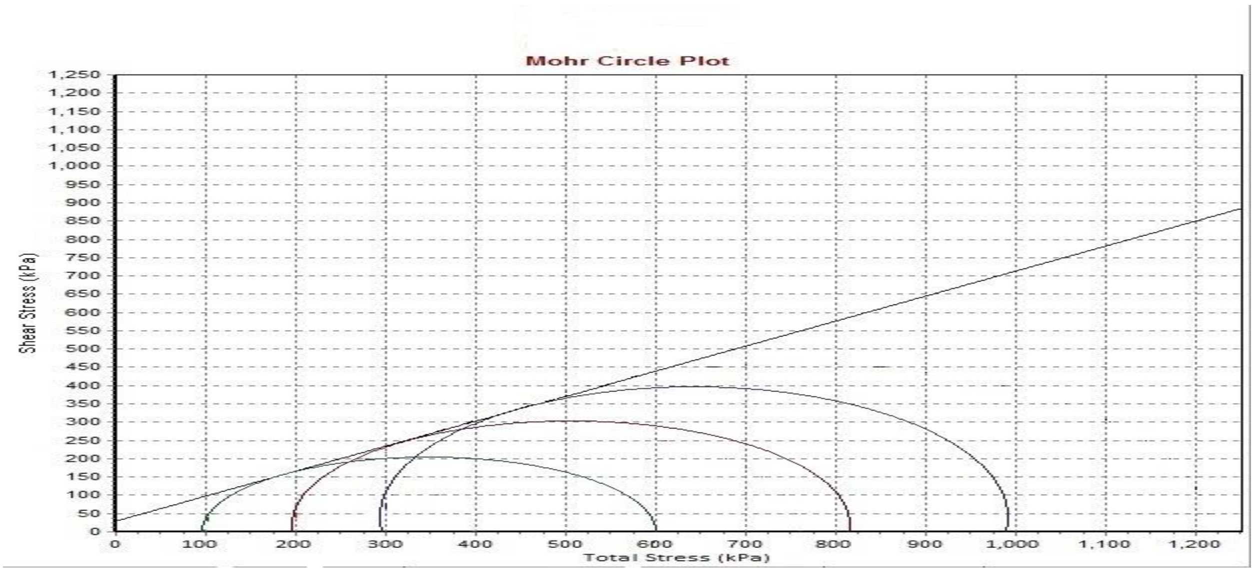
From the above graphs the unconfined compressive strength of different mix proportions, the maximum unconfined compressive strength was found out to be 389.3 kN/m^2.

4.2.3.5 Triaxial Test of different mix proportions

To obtain the shear parameter, triaxial test are conducted on the different mix proportions. The test was conducted on three different cell pressure i.e. 98.07 kPa (1 kg/cm^2), 196.14 kPa (2 kg/cm^2), 294.21 kPa (3 kg/cm^2). The experimental observations and Mohr's circle of various mix proportions are as follows:

c = 25.8 kN/m^2, ϕ = 32.3°

Fig. 4.30 Triaxial Test: 90% red mud + 10% pond ash



c = 30.1 kN/m^2, ϕ = 34.4°

Fig. 4.31 Triaxial Test: 80% red mud + 20% pond ash

c = 17.2 kN/m^2, ϕ = 31.7°

Fig. 4.32 Triaxial Test: 70% red mud + 30% pond ash

c = 15.05 kN/m^2, ϕ = 26.7°

Fig. 4.33 Triaxial Test: 60% red mud + 40% pond ash

c = 15.05 kN/m^2, ϕ = 24.5°

Fig. 4.34 Triaxial Test: 50% red mud + 50% pond ash

From the above Mohr's circle the maximum value of cohesion (c) and the angle of internal friction (Φ) is maximum in 80% red mud + 20% pond ash mix i.e. 30.1 kN/m^2 and 34.4° respectively. The higher cohesion value depends upon intermolecular space between particles, surface area to volume ratio and moisture content. The angle of friction value determines the intermolecular interaction. It depends upon arrangement of particles and interlocking capability of constituent particles.

4.2.3.6 Permeability Test of different mix proportions

The average value of coefficient of permeability of different mix proportions were determined as per IS: 2720 (Part 36) 1975. The samples were compacted in the permeability mould to the desired MDD. Then the average permeability was determined for each proportions by allowing water to flow through the samples under falling head.

Table 4.7 Falling head permeability: 90% red mud + 10% pond ash

Initial Head, h_1 (cm)	Final Head, h_2 (cm)	Time taken (s)	Area of cross section, A (cm^2)	Cross sectional area of pipe, a (cm^2)	Length of the sample, L (cm)	Coefficient of permeability, k (cm/s)
5.7	2	18900	78.53	5.72	12.7	5.12×10^{-5}
8.5	6.2	5672	78.53	5.72	12.7	5.14×10^{-5}

Table 4.8 Falling head permeability: 80% red mud + 20% pond ash

Initial Head, h_1 (cm)	Final Head, h_2 (cm)	Time taken (s)	Area of cross section, A (cm^2)	Cross sectional area of pipe, a (cm^2)	Length of the sample, L (cm)	Coefficient of permeability, k (cm/s)
100	85.2	2400	78.53	5.72	12.7	6.16×10^{-5}
85.5	24.5	18660	78.53	5.72	12.7	6.18×10^{-5}

Table 4.9 Falling head permeability: 70% red mud + 30% pond ash

Initial Head, h_1 (cm)	Final Head, h_2 (cm)	Time taken (s)	Area of cross section, A (cm^2)	Cross sectional area of pipe, a (cm^2)	Length of the sample, L (cm)	Coefficient of permeability, k (cm/s)
92.5	87.5	3758	78.53	5.72	12.7	1.36×10^{-5}
87.5	61.3	24278	78.53	5.72	12.7	1.35×10^{-5}

Table 4.10 Falling head permeability: 60% red mud + 40% pond ash

Initial Head, h_1 (cm)	Final Head, h_2 (cm)	Time taken (s)	Area of cross section, A (cm^2)	Cross sectional area of pipe, a (cm^2)	Length of the sample, L (cm)	Coefficient of permeability, k (cm/s)
95.3	81.7	11758	78.53	5.72	12.7	1.21×10^{-5}
81.7	68.5	13131	78.53	5.72	12.7	1.24×10^{-5}

Table 4.11 Falling head permeability: 50% red mud + 50% pond ash

Initial Head, h_1 (cm)	Final Head, h_2 (cm)	Time taken (s)	Area of cross section, A (cm^2)	Cross sectional area of pipe, a (cm^2)	Length of the sample, L (cm)	Coefficient of permeability, k (cm/s)
99.3	88.3	10234	78.53	5.72	12.7	1.06×10^{-5}
88.3	41	67511	78.53	5.72	12.7	1.05×10^{-5}

From the above permeability data it is noted that coefficient of permeability (k) of 80% red mud + 20% pond ash is low as compared to other mix proportions i.e. 5.12×10^{-5} cm/s, due to increase in the MDD value then the permeability increases with increase in pond ash content, due to the lack of interlocking between particle.

4.2.3.7 Plasticity characteristics of different mix proportions

The liquid and plastic limits of different mix proportions found out as per IS: 2720 (Part V) 1985. The values of Atterberg's limit of different proportions are as follows:

Table 4.12 Consistency limit and Plasticity Indices of different mix proportions

Mix Proportions	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index
100% red mud	29	23	6
90% red mud + 10 % pond ash	28.5	24.8	4
80% red mud + 20 % pond ash	27.3	24	3
70% red mud + 30 % pond ash	26.5	23.8	3
60% red mud + 40 % pond ash	25.3	23	2
50% red mud + 50 % pond ash	24.8	22.7	2

From the above values it has been observed that the plasticity index decreases as percentage of pond ash increases.

4.2.3.8 pH of different mix proportions

The pH value for various mix proportions were determined as per IS: 2720 (Part 26) 1987. The pH of different mix proportions are as follows:

Table 4.13 pH values of different mix proportions

Mix Proportions	pH value
100% red mud	9.74
90% red mud + 10% pond ash	9.12
80% red mud + 20% pond ash	8.73
70% red mud + 30% pond ash	8.68
60% red mud + 40% pond ash	8.51
50% red mud + 50% pond ash	8.37
100% pond ash	7.53

From the above pH values it is noted that red mud is a highly alkaline material and pond ash is slightly alkaline material. The pH values decreases as the percentage of pond ash increases.

Table 4.14 Comparative study of various mix proportions

Proportions (%)		Sp. Gravity	Plasticity Index	MDD	Direct Shear Test		Triaxial Shear Test		UCS (kN/m^2)	pH	Permeability (cm/s)
Red Mud	Pond Ash				c	ϕ	c	ϕ			
100	0	3	6	16.9	26.4	34.3	25.8	33.2	502.4	9.74	1.6×10^{-6}
90	10	2.89	4	15.3	26	34.4	25.8	32.3	260.7	9.12	5.13×10^{-5}
80	20	2.62	3	15.84	28	35.9	30.1	34.4	389.3	8.73	6.17×10^{-5}
70	30	2.44	3	15.37	17.3	32.3	17.2	21.7	198.4	8.68	1.36×10^{-5}
60	40	2.41	2	14.5	16.7	29.5	15.05	26.7	209	8.51	1.23×10^{-5}
50	50	2.24	2	14.2	15.9	26.7	15.05	24.5	170.2	8.37	1.05×10^{-5}

Where,

MDD in kN/m^3

c in kN/m^2

ϕ in degree

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The following observations can be made based on the above from Chapter 1 to Chapter 4. Production of red mud and pond ash is increased day by day for which storage is a major concern because now a days land is precious. Though, several studies have been made to use red mud as an alternate embankment material, in this study red mud and pond ash combinedly used as embankment and as filling material.

i. The strength parameter are the only governing criteria for stability of slopes for construction of embankment. From the analysis of different mix proportions of red mud and pond ash, mix proportion having 80% red mud and 20% pond ash shows higher MDD over other mix proportion i.e. 15.84 kN/m^3 (15.3 kN/m^3 for 90% red mud + 10% pond ash and 14.19 kN/m^3 for 50% red mud + 50% pond ash). Also it shows higher cohesion and angle of friction value i.e. 30.1 kN/m^2, 34.4° respectively which is greater than other mix proportions.

ii. As the percentage of pond ash increases the pH value of the mix proportion decreases. So it’s better to use a low pH mix proportion than red mud.

iii. Plasticity index also decreases with increase in pond ash content in the mix proportions. So, it’s better to use a low plasticity mix which can be easily handle during construction embankment or as filling material.

5.2 Future Scope

The investigation has certain limitation and hence all the factors that could not be addressed in time. So the future research should incorporate the following aspects in detail

i. The geo-environmental aspects i.e. leaching characteristics of the mix proportions should be checked.

CHAPTER 6

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